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Effect of Cover Crops Alfalfa, Red Clover, and Perennial Ryegrass on Soybean Cyst Nematode Population and Soybean and Corn Yields in Minnesota

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ABSTRACT

The effects of alfalfa, red clover, and perennial ryegrass as cover crops on soybean cyst nematode (SCN) and soybean and corn yields were evaluated in Waseca, Lamberton, and Rosemount, MN. The cover crops were interseeded in soybean at 0 or 2 wks after planting soybean in 2002 and killed with herbicide before planting corn in 2003. As expected, SCN-susceptible soybean supported higher SCN population density than SCN-resistant soybean. Reduction of SCN population density by red clover (up to 40%) and alfalfa (up to 55%) was observed in some sampling occasions at Lamberton and Rosemount, probably due to reduced soybean growth, but the effect was inconsistent. No significant reduction of SCN population by the two crops was detected at Waseca. While perennial ryegrass did not affect SCN population density in most cases, up to 46% higher egg population densities were observed in the perennial ryegrass treatment as compared to the control at Waseca. SCN-resistant soybean produced higher yield than susceptible soybean at all sites. While alfalfa reduced soybean yield at Lamberton (up to 50%) and Rosemount (up to 11%), red clover and perennial ryegrass reduced soybean yield only at Lamberton (up to 38%) and Waseca (up to 34%), respectively. No difference in corn yield was observed at Waseca. At Lamberton, alfalfa and red clover planted at the time of planting soybean reduced corn yield in the following year 17 and 13%, respectively, and perennial ryegrass planted 2 wks after planting soybean reduced corn yield 13%. At Rosemount, significant reduction of corn yield was observed with red clover (15–21%) interseeded in SCN-susceptible soybean and with alfalfa (12%) and red clover (12%) interseeded in SCN-resistant soybean at the time of planting soybean. The results suggest that an even later planting date of cover crops in soybean may reduce yield loss due to competition and make these cover crops more appropriate for use in the soybean-corn rotation in Minnesota.

The corn (*Zea mays* L.)-soybean (*Glycine max* (L.) Merr.) rotation has become a predominant production system that is currently practiced on over 20 million hectares in the North Central region in the United States. During the past three decades, soybean cyst nematode (SCN), *Heterodera glycines* Ichinohe, has become the major pest problem in the corn-soybean production system in the region (Wrather et al., 2001; Monson and Schmitt, 2004). Management of the nematode has been dependent on planting resistant cultivars and the use of crop rotations (Schmitt, 1991; Niblack and Chen, 2004). In spite of the widespread availability of resistant cultivars, management of SCN has proven difficult. The distribution of SCN is expanding and severity of SCN damage continues to increase in the North Central region. There are several reasons why SCN remains as the most economically important pest of soybeans. Perhaps the most significant biological factor is the high genetic variability of SCN with regard to parasitism of soybean cultivars which makes it difficult to select resistant cultivars. In addition, resistant cultivars impose selection pressure on the nematode resulting in shifts from one HG Type (race) to another (Young, 1995, 1998). Although resistant cultivars generally produce higher yields in SCN-infested fields, high SCN population densities can cause significant yield loss even to a resistant cultivar (MacGuidwin et al., 1995; Tylka, 1997). Furthermore, there is a yield penalty for using a resistant cultivar in noninfested fields or those with low levels of infestation when compared with high-yielding susceptible cultivars (S. Chen et al., unpublished). This is probably due to the genetic linkage of low yield with SCN-resistance (Mudge et al., 1996). The corn–soybean rotation is conducive to SCN population development. After only one season the SCN population density can increase to a level so high that several years of growing non-host crops are needed to reduce the population density to below the yield-loss threshold (Chen et al., 2001). The SCN survival rate in the North Central region is higher compared with that in the southern regions (Riggs et al., 2001). For these reasons, alternative tactics are needed for long-term effective management of SCN and a diversified corn-soybean cropping system in which more crops are included may be useful in managing the nematode in the North Central region.

Introduction of cover crops into the system is one way to add diversity. Depending on geographic locations and cropping systems, benefits of growing cover crops may include improvement of overall soil and groundwater quality, reduction of soil erosion, suppression of weeds, pathogens and pests, increase of cash crop productivity, and enhancements of environment quality

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Abbreviations: PCF, population change factor = egg population density at harvest/egg population density at planting in the same year; SCN, soybean cyst nematode; WAP, weeks after planting soybean.

(Sullivan, 2003; Snapp et al., 2005). However, inappropriate use of cover crops may result in increased production costs associated with growing the cover crops, and may adversely affect crop production (Snapp et al., 2005).

Cover crops either in rotation or interseeded with primary crops have been used for managing a number of plant-parasitic nematodes (Duncan and Noling, 1998; Abawi et al., 2000). Effects of cover crops on plant-parasitic nematodes varied depending on species of cover crops and nematodes (Phatak, 1998; McSorley, 1998; Abawi et al., 2000). They may suppress plant-parasitic nematode populations by acting as a non-host or a poor host, producing allelochemicals that are toxic or inhibitory, providing niches for antagonistic flora and fauna, and trapping nematodes (Wang et al., 2002). Some plants are known to produce nematicidal compounds. For example, some species of *Brassica* produce glucosinolates that degrade in soil to form isothiocyanates, the *Tagetes* species produce terthienyl, and the *Crotalaria* species produce monocrotaline; all of these compounds have nematicidal properties (Chitwood, 2002). Several studies demonstrated that some cover crops such as sunn hemp (*Crotalaria juncea*) and castor bean (*Ricinus communis*) may enhance activities of microorganisms antagonistic to nematodes (Kloepper et al., 1992; Wang et al., 2002; Wang and McSorley, 2002).

There have been a few studies of the potential of using cover crops for SCN management (Niblack and Chen, 2004). Studies performed in the greenhouse to evaluate host range (Riggs, 1980, 1992; Mosjidis et al., 1994; Valle et al., 1995), effect of plants on hatch and development (Sortland and MacDonald, 1987; Schmitt and Riggs, 1991), and nematicidal effect of crop residues (Riga et al., 2001) have provided useful information in selecting cover crops for field use in SCN management. Bahiagrass (*Paspalum notatum* Flugger), American jointvetch (*Aeschynomene americana* L.), and hairy indigo (*Indigofera hirsuta* L.) used as rotation cover crops were effective in reducing the SCN population densities and increasing soybean yield compared with soybean in monoculture (Rodriguez-Kabana et al., 1989, 1990, 1991; Weaver et al., 1998). Annual ryegrass (*Lolium multiflorum* Lam.) planted as a winter cover crop reduced SCN population density compared with fallow, but soybean yield was lower following the cover crop than fallow treatment (Pedersen and Rodriguez-Kabana, 1991).

Alfalfa (*Medicago sativa* L.), red clover (*Trifolium pratense* L.), and perennial ryegrass (*Lolium perenne* L.) are three crops that are currently being evaluated in a number of studies as cover crops in soybean/corn production system, to reduce soil erosion, enhance soil fertility, and enhance biodiversity of the agricultural ecosystem in Minnesota. In this study, these three crops were evaluated as cover crops interseeded in soybean fields for their effect on SCN population densities and soybean and corn yields in Waseca, Lamberton, and Rosemount, Minnesota. Interseeding was selected, instead of utilizing these species as winter cover crops, to examine their potential as nonhosts or trap crops and to evaluate their impact on other aspects of the production system such as summer weed populations. The aim of the study was to determine whether there is any added value in SCN management besides the agronomic consideration of these species as potential cover crops in the upper Midwest.

The effect of red clover on SCN has been studied previously in vitro and in the field. While Aiba and Mitsui (1995) observed that red clover stimulated hatch of SCN, both an inhibitory effect (Kushida et al., 2002) or no effect (Schmitt and Riggs, 1991) of red clover have been reported. The nematode was able to penetrate red clover, but none developed to adult females (Kushida et al., 2002; S. Vetter, personal communication). In field studies, red clover as a rotation crop was effective in lowering SCN population density (Shimizu et al., 1989; Kushida et al., 2002). Alfalfa is a poor host or nonhost of SCN (Riggs and Hamblen, 1962, 1966; Sortland and MacDonald, 1987; Riggs, 1992). Schmitt and Riggs (1991) reported that alfalfa did not increase the number of SCN second-stage juveniles hatched in greenhouse pot soil as compared with no-plant fallow, and the nematodes did not develop to mature females and reproduce on alfalfa. In a greenhouse pot experiment, alfalfa lowered SCN population density compared with fallow control (Vetter et al., 2005). When used as rotation crops, leguminous crops (including red clover and alfalfa) were better than monocots (including the common rotation crop corn) in lowering SCN population density both in greenhouse (Vetter et al., 2005) and field (Miller et al., 2006) studies. Perennial ryegrass is assumed to be a nonhost of SCN because no species of the family Poaceae has been reported as a host of the nematode (Riggs and Hamblen, 1966; Riggs, 1992), and we are unaware of any study of its effect on SCN population in the literature.

MATERIALS AND METHODS

Experiment Establishment and Maintenance

The experiment was conducted at three SCN-infested field sites in Waseca, Rosemount, and Lamberton, Minnesota in 2002 and 2003. All fields were previously in a corn–soybean rotation with soybean grown in 2001. In the spring of 2002, the Waseca, Lamberton, and Rosemount sites had natural infestations of SCN of 2 480, 9 159 and 9 192 eggs 100-cm^{-3}, respectively. Each site had unique soil properties. At Waseca, the soil was a Canisteo clay loam (Typic Endoaquolls) with 27.3% sand, 36.5% silt, 36.2% clay, 6% organic matter, and a pH of 7.5. At Lamberton, the soil was a Knoke silty clay loam (Cumulic Vertic Endoaquolls) with 22.8% sand, 40.9% silt, 36.3% clay, 6% organic matter, and a pH of 7.6. The soil at Rosemount was a Waukegan silt loam (Typic Hapludolls) with 19.4% sand, 54.8% silt, 25.8% clay, 4.2% organic matter, and a pH of 6.7.

The experiment was a 2 × 9 factorial treatment design with eight replicates arranged in completely randomized blocks. The first factor contained two soybean cultivars: SCN-resistant 2121 NNR (Gold Country) and SCN-susceptible 92B36 (Pioneer) at Waseca and Lamberton, and SCN-resistant D151RR/N (Garst) and SCN-susceptible AG1602RR (AsGrow) at Rosemount. The other factor included nine treatment combinations of three cover crops (alfalfa, red clover, and perennial ryegrass) and no-cover crop controls with two planting dates for the cover crops and three crop-appropriate herbicide applications (Table 1).

Plots were 7.6 m long and 3 m wide. The cover crops were interseeded between soybean rows at planting in May 2002 or 2 wk after planting. Soybean was planted in four 75-cm spacing rows with a seeding rate of 432 000 seeds ha^{-1}. Seeds of alfalfa, red clover, and perennial ryegrass were broadcasted with hand at rates of 16.8, 16.8, and 22.4 kg ha^{-1}, respectively. The seeds were briefly incorporated into soil with a harrow. For weed control, during the third week of June 2002 the perennial rye and its control (no cover) plots were treated with 0.077 kg ha^{-1} quizalofop-p-ethyl (2-[4-(6-chloroquinoxalin 2-yl)oxyphenoxy]propianic acid) and 1.121 kg ha^{-1} bentazon (3-isopropyl-1H-2,1,3-benzothiadiazin-4(3H)-one 2, 2-dioxide(1)); alfalfa and red clover and their control plots were treated with 0.07 kg ha^{-1} imazethapyr (2-[4,5-dihydro-4-methyl-4(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid). A plot with no cover crop treated with 0.841 kg ha^{-1} glyphosate (2-phosphonomethylamino acetic acid) was included as conventional weed control for a comparison purpose. Herbicides were also used to manage weed specific to the sites. At Waseca 0.105 kg ha^{-1} lactofen (5-[2chloro-4-(trifluromethyl) phenoxy]-2-nitro-benzoic acid1-ethoxyearbonylethylester) was used to control waterhemp (*Amaranthus tuberculatus* (Moq.) Sauer). Two applications of 0.077 kg ha^{-1} quizalofop-p-ethyl were applied in all plots at the Lamberton site to control problematic grass weeds.

Strip tillage was used in the fall of 2002 after harvesting soybean at all sites. No tillage was used in the spring of 2003 before planting corn at Lamberton and Rosemount sites, but the plots were accidentally tilled by the field owner in the spring of 2003 at Waseca site. No fertilizer was applied in the soybean growing season in 2002, and 135 kg ha^{-1} urea (Agrotain) was applied to the surface of the soil before planting corn in May 2003. Glyphosate at 0.841 kg ha^{-1} and dicamba (3,6-dichloro-2-methoxybenzoic acid) at 0.561 kg ha^{-1} were applied in all plots in early May at Lamberton and Rosemount to kill the cover crops after planting corn and to control weeds. The corn cultivar Dekalb DK42–93 resistant to glyphosate was grown on all plots, and glyphosate at 0.578 kg ha^{-1} was applied 3–4 wk after planting corn at the three sites in 2003.

Data Collection

Nematode egg densities were determined at planting, midseason (2 mo after planting), and harvest in 2002, and at planting and harvest in 2003. A composite soil sample consisting of 20 cores was taken with a 2.5-cm-diameter soil probe to a 20-cm depth across the central area (within and between rows) of approximately 6 × 1.5 m of each plot. The soil samples were stored in a cool room (4°C) before being processed. Each soil sample was smashed on 1 × 1 cm screen to break large aggregates, and thoroughly mixed. Cysts were extracted from a subsample of 100 cm^3 soil with a semiautomatic elutriator (Byrd et al., 1976) and separated from soil particles and debris with centrifugation in 63% (w/v) sucrose solution. Eggs were released from the cysts mechanically (Faghihi and Ferris, 2000), collected into a 50-mL tube, and counted. Nematode population density was expressed as number of eggs 100-cm^{-3} of soil.

Soybean yields in 2002 and corn yields in 2003 were measured from 6.1-m length of the two central rows with a small plot combine. The soybean yield was standardized at 130 g kg^{-1} moisture, and corn yield was standardized to 155 g kg^{-1}.

Data Analysis

For the plots in which egg densities at planting (Pi) were more than 500 eggs 100-cm^{-3}, the SCN population change factor (PCF) were computed by dividing Pf (egg population density at harvest) by Pi each year. Population change factor values less than 1 indicate decreases, values greater than 1 indicate increases, and a value equal to 1 indicates no change in the nematode population. Nematode egg counts and PCF were transformed with $\log_{10}(x)$ to improve homogeneity of variances before being subjected to analyses of variance (ANOVA). Yields were not transformed for the ANOVA. Because interactions between field site and treatment were significant for most measurements, the three sites were analyzed separately. Two-way factorial ANOVA was performed to determine the main effects at each site. The means were separated by least significant difference (LSD) at $\alpha = 0.05$.

Table 1. ***Heterodera glycines*** **population response to soybean cultivar and cover crop treatment at Waseca, MN.†**

Treatment factors	Treatment level‡	2002 Soybean			2003 Corn		PCF§	
		At planting	Midseason	At harvest	At planting	At harvest	2002	2003
		eggs 100-cm^{-3} soil						
Soybean cultivar	SCN-susceptible	2 257	4 510a	6 272a	4 370a	2967a	4.01a	0.79
	SCN-resistant	1 839	3 420b	3 199b	2 663b	1908b	2.43b	0.78
Cover crop treatment	No cover/glyphosate	1 898	3 964	4 416	3 705abcd	2 641ab	2.92	0.83
	No cover/imazethapyr	2 048	3 472	4 800	3 791abc	2 298b	3.25	0.68
	No cover/quizalofop-p-ethyl + bentazon	1 929	4 059	4 569	2 963d	2 212b	3.20	0.85
	Alf, 0 WAP/imazethapyr	1 758	3 930	4 803	3 083cd	2 444b	3.11	0.87
	RC, 0 WAP/imazethapyr	2 104	3 908	4 573	3 284bcd	2 300b	2.84	0.75
	Alf, 2 WAP/imazethapyr	2 485	3 991	4 136	2 927cd	2 204b	2.92	0.84
	RC, 2 WAP/imazethapyr	2 319	4 219	5 190	3 603abcd	2 055b	3.33	0.69
	PR, 0 WAP/quizalofop-p-ethyl + bentazon	2 239	4 500	5 506	4 050ab	3 237a	3.71	0.89
	PR, 2 WAP/quizalofop-p-ethyl + bentazon	1 651	3 641	4 625	4 245a	2 547ab	3.72	0.66
ANOVA								
Block		**	***	*	NS	NS	***	NS
Soybean cultivar (S)		NS	***	***	***	***	***	NS
Cover crop (C)		NS	NS	NS	*	**	NS	NS
S × C		NS	NS	NS	NS	NS	NS	NS

† Data were transformed with $\log_{10}(x)$ before being subjected to analysis of variance (ANOVA). The values are means of main effects with eight replicates. The values followed by different letters in the column within the same factor are significant different according to the least significant difference (LSD) test at $P \leq 0.05$.

‡ Alf, RC, and PR represent alfalfa, red clover, and perennial ryegrass, respectively. The cover crops were interseeded with soybean at planting (0 WAP) or 2 wk after planting (2 WAP) soybean in 2002, and corn was planted in 2003.

§ PCF is population change factor (egg population density at harvest/egg population density at planting).

RESULTS

SCN Egg Population Density

The SCN egg densities at Waseca, Lamberton, and Rosemount are presented in Tables 1, 2, and 3, respectively. There was no significant difference in SCN populations at planting in 2002 among the treatments. Egg population densities were higher in plots planted to SCN-susceptible than SCN-resistant soybean at all sampling occasions from mid-season in 2002 to the end of season in 2003 at all three sites except in 2002 midseason at Rosemount. Analysis of variance for SCN population density indicated no significant soybean cultivar × cover crop treatment interaction at any location in any season. The effect of cover crop treatments on the egg densities, however, varied among the three sites.

At Waseca, no cover crop effect on egg population was observed in 2002. At planting in 2003, the egg population density was higher in the perennial ryegrass treatment than its herbicide-only control and alfalfa treatments (Table 1). At the end season in 2003, the egg population density in the perennial ryegrass planted at 0 wk after planting soybean (WAP) was higher than alfalfa and red clover planted 0 or 2 WAP. The egg population density in this treatment also was higher than in its herbicide-only control. No differences were observed among other treatments (Table 1).

At Lamberton, red clover planted at 0 or 2 WAP reduced SCN egg population density at midseason in 2002 compared with its herbicide-only control. Perennial ryegrass planted at 0 WAP resulted in higher egg population density than perennial ryegrass planted at 2 WAP and its herbicide-only control (Table 2). At the end of the 2002 season, red clover planted at 0 or 2 WAP and alfalfa planted at 2 WAP reduced egg population density compared with the control. At the end of 2003 season, alfalfa and red clover planted at 0 WAP reduced egg population density compared with the control. No other differences were observed among the treatments (Table 2).

At Rosemount, alfalfa and red clover planted at 0 and 2 WAP reduced egg population density at the end of season in 2002. Lower egg population densities compared with control at planting in 2003 were observed for alfalfa planted at 0 and 2 WAP and red clover planted at 2 WAP. By the end of season in 2003, only the egg population density in red clover planted at 2 WAP was lower than the control. No differences among other treatments were observed, and perennial ryegrass did not increase or reduce egg density compared with its herbicide-only control at this site (Table 3).

SCN Population Change During a Single Season

Treatment effects on PCF during a single season varied among the three sites (Tables 1, 2, and 3). At Waseca, differences between the two soybean cultivars were only observed in 2002, with SCN-resistant soybean resulting in lower population change factor values than SCN-susceptible soybean, though the PCF values were greater than 1 on both resistant and susceptible cultivars at this location (Table 1). The cover crop treatments did not affect the seasonal population change at this location. At Lamberton in 2002, the PCF value was higher for SCN-susceptible soybean than SCN-resistant soybean, and SCN-resistant cultivar suppressed population development. In contrast, in 2003 when corn was grown, the PCF was higher in plots following SCN-resistant soybean than following SCN-susceptible soybean (Table 2). The population remained unchanged following SCN-resistant soybean and declined following SCN-susceptible soybean. At Lamberton, cover crop effects on the PCF were observed only in the soybean season. Alfalfa and red clover planted 2 WAP resulted in lower PCF values than the herbicide-only control and reduced the SCN population that year (Table 2). At Rosemount the effect of SCN resistance on seasonal population changes was similar to that at Lamberton, with lower values in SCN-resistant plots in 2002, but

Table 2. *Heterodera glycines* population response to soybean cultivar and cover crop treatment at Lamberton, MN.†

Treatment factors	Treatment level‡	2002 Soybean At planting	2002 Soybean Midseason	2002 Soybean At harvest	2003 Corn At planting	2003 Corn At harvest	PCF§ 2002	PCF§ 2003
		eggs 100-cm^{-3} soil						
Soybean cultivar	SCN-susceptible	9 611	9 535a	9 350a	7 806a	5 774a	1.44a	0.85b
	SCN-resistant	8 707	6 528b	5 040b	4 675b	4 449b	0.66b	1.00a
Cover crop treatment	No cover/glyphosate	9 748	8 522abcd	8 428ab	7 372	5 106ab	1.33a	0.75
	No cover/imazethapyr	8 563	9 639a	9 984a	6 161	6 682a	1.19a	1.33
	No cover/quizalofop-p-ethyl + bentazon	8 705	5 655d	8 153ab	6 536	5 466ab	0.98ab	1.01
	Alf, 0 WAP/imazethapyr	8 694	8 389abc	6 681abcd	6 100	4 328bc	0.84ab	0.74
	RC, 0 WAP/imazethapyr	7 597	7 834bcd	6 453bcd	5 347	3 356c	1.33ab	0.80
	Alf, 2 WAP/imazethapyr	9 994	7 452abcd	5 923cd	6 102	5 660ab	0.68bc	0.89
	RC, 2 WAP/imazethapyr	10 780	7 463cd	5 258d	6 306	5 291ab	0.71c	0.97
	PR, 0 WAP/quizalofop-p-ethyl + bentazon	10 589	11 238ab	7 620abc	6 646	5 901ab	1.14ab	1.01
	PR, 2 WAP/quizalofop-p-ethyl + bentazon	7 763	6 091cd	6 250bcd	5 594	4 216bc	1.23ab	0.86
ANOVA								
Block		***	***	***	***	***	***	NS
Soybean cultivar (S)		NS	***	***	***	***	***	*
Cover crop (C)		NS	*	*	NS	*	*	NS
S × C		NS	NS	NS	NS	NS	NS	NS

† Data were transformed with $\log_{10}(x)$ before being subjected to analysis of variance (ANOVA). The values are means of main effects with eight replicates. The values followed by different letters in the column within the same factor are significant different according to the least significant difference (LSD) test at $P \leq 0.05$.

‡ Alf, RC, and PR represent alfalfa, red clover, and perennial ryegrass, respectively. The cover crops were interseeded with soybean at planting (0 WAP) or 2 wk after planting (2 WAP) soybean in 2002, and corn was planted in 2003.

§ PCF is population change factor (egg population density at harvest/egg population density at planting).

Table 3. ***Heterodera glycines*** **population response to soybean cultivar and cover crop treatment at Rosemount, MN.†**

Treatment factor	Treatment level‡	2002 Soybean At planting	2002 Soybean Midseason	2002 Soybean At harvest	2003 Corn At planting	2003 Corn At harvest	PCF§ 2002	PCF§ 2003
			eggs 100-cm^{-3} soil					
Soybean cultivar	SCN-susceptible	9 141	4 565	9 190a	6 853a	3 000a	1.52a	0.51b
	SCN-resistant	9 242	3 786	3 503b	2 540b	1 893b	0.47b	0.81a
Cover crop treatment	No cover/glyphosate	8 897	4 202	9 378a	6 255a	3 153a	1.27a	0.57ab
	No cover/imazethapyr	10 189	4 554	8 022a	5 802a	2 588ab	1.27a	0.52bc
	No cover/quizalofop-p-ethyl + bentazon	9 652	3 782	6 703ab	4 017abcd	2 783ab	1.16a	0.79ab
	Alf, 0 WAP/imazethapyr	10 196	3 797	4 794d	3 495cd	2 558ab	0.78b	0.89a
	RC, 0 WAP/imazethapyr	9 491	4 414	5 597cd	4 361abcd	1 953b	0.78b	0.52bc
	Alf, 2 WAP/imazethapyr	8 620	4 145	5 300bcd	3 957bcd	2 053ab	0.88ab	0.70ab
	RC, 2 WAP/imazethapyr	8 200	4 080	5 634cd	3 943d	1 174c	0.94ab	0.50c
	PR, 0 WAP/quizalofop-p-ethyl + bentazon	8 569	4 055	5 319bcd	4 905abc	2 766ab	0.84ab	0.76ab
	PR, 2 WAP/quizalofop-p-ethyl + bentazon	8 909	4 549	6 369abc	5 536ab	2 992a	1.01a	0.68ab
ANOVA								
Block		***	***	**	*	**	***	**
Soybean cultivar (S)		NS	NS	***	***	***	***	***
Cover crop (C)		NS	NS	***	**	***	*	*
S × C		NS	NS	NS	NS	NS	NS	NS

† Data were transformed with $\log_{10}(x)$ before being subjected to analysis of variance (ANOVA). The values are means of main effects with eight replicates. The values followed by different letters in the column within the same factor are significant different according to the least significant difference (LSD) test at $P \leq 0.05$.
‡ Alf, RC, and PR represent alfalfa, red clover, and perennial ryegrass, respectively. The cover crops were interseeded with soybean at planting (0 WAP) or 2 wk after planting (2 WAP) soybean in 2002, and corn was planted in 2003.
§ PCF is population change factor (egg population density at harvest/egg population density at planting).

higher values in 2003 (Table 3). Cover crop treatments affected seasonal population changes both years. In the 2002 soybean season, the PCF was lower in treatments of alfalfa and red clover planted 0 WAP than in the herbicide-only control, and these cover crop treatments reduced the SCN population over the season. In the 2003 corn season, the PCF was higher in the treatment of alfalfa planted 0 WAP than in the herbicide-only control, though in both treatments the SCN population decreased over time (Table 3).

Crop Yields

Soybean Yield in 2002

The overall soybean yield at Lamberton and Waseca was low in part due to iron-deficiency chlorosis damage. As expected, the SCN-resistant cultivar produced higher yield than the SCN-susceptible cultivar at all three sites (Table 4). Cover crops affected soybean yield differently at the three locations. At Waseca, perennial ryegrass resulted in lower yield compared with its control. The highest yields were observed in the treatments of no-cover with glyphosate or quizalofop-p-ethyl + bentazon herbicide applications. The red clover and alfalfa planted at 0 and 2 WAP resulted in lower yield than the treatment of no-cover with glyphosate, but similar low yield as the control (no cover with imazethapyr) (Table 4). At Lamberton, alfalfa and red clover planted 0 WAP and alfalfa planted 2 WAP resulted in lower yield than the appropriate control. Although the yields in treatments of cover crops planted at 0 WAP were higher numerically than at 2 WAP for all three crops, the difference was not significant (Table 4). At Rosemount, only alfalfa planted at 0 WAP suppressed soybean yield

Table 4. 2002 soybean yield response to cultivar and cover crop treatment in fields infested with ***Heterodera glycines*** **in Minnesota.†**

Treatment factor	Treatment level‡	Field sites: Waseca	Field sites: Lamberton	Field sites: Rosemount
			kg ha^{-1}	
Soybean cultivar	SCN-susceptible	1 216b	688b	2 457b
	SCN-resistant	1 971a	1 279a	2 667a
Cover crop treatment	No cover/glyphosate	2 034a	1 187ab	2 807a
	No cover/imazethapyr	1 553cd	1 134ab	2 723ab
	No cover/quizalofop-p-ethyl + bentazon	1 959ab	1 318a	2 572abc
	Alf, 0 WAP/imazethapyr	1 308d	563d	2 434c
	RC, 0 WAP/imazethapyr	1 320d	699cd	2 505bc
	Alf, 2 WAP/imazethapyr	1 705bc	713cd	2 636abc
	RC, 2 WAP/imazethapyr	1 523cd	911bc	2 520bc
	PR, 0 WAP/quizalofop-p-ethyl + bentazon	1 299d	1 061ab	2 462c
	PR, 2 WAP/quizalofop-p-ethyl + bentazon	1 642c	1 263a	2 397c
ANOVA				
Block		***	***	***
Soybean cultivar (S)		***	***	***
Cover crop (C)		***	***	*
S × C		NS	NS	NS

† The values are means of main effects with eight replicates. The values followed by different letters in the column within the same factor are significant different according to the least significant difference (LSD) test at $P \leq 0.05$.
‡ Alf, RC, and PR represent alfalfa, red clover, and perennial ryegrass, respectively. The cover crops were interseeded with soybean at planting (0 WAP) or 2 wk after planting (2 WAP) soybean in 2002, and corn was planted in 2003.

Table 5. 2003 corn yield response to soybean cultivar and cover crop treatment in the previous season in fields infested with *Heterodera glycines* in Minnesota.†

Treatment factor	Treatment level‡	Field sites		
		Waseca	Lamberton	Rosemount
		kg ha^{-1}		
Soybean cultivar	SCN-susceptible	13 391	9 229	8 153
	SCN-resistant	13 234	8 972	8 188
Cover crop treatment	No cover/glyphosate	13 469	9 808a	8 354
	No cover/imazethapyr	13 016	9 820a	8 765
	No cover/quizalofop-p-ethyl + bentazon	13 477	9 718a	8 284
	Alf, 0 WAP/imazethapyr	13 141	8 562bc	8 096
	RC, 0 WAP/imazethapyr	13 487	8 183d	7 599
	Alf, 2 WAP/imazethapyr	13 789	9 310ab	8 609
	RC, 2 WAP/imazethapyr	13 041	9 001abc	7 572
	PR, 0 WAP/quizalofop-p-ethyl + bentazon	12 909	9 012abc	8 028
	PR, 2 WAP/quizalofop-p-ethyl + bentazon	13 485	8 490cd	8 230
ANOVA				
Block		***	***	***
Soybean cultivar (S)		NS	NS	NS
Cover crop (C)		NS	**	***
S × C		NS	NS	***

† The values are means of main effects with eight replicates. The values followed by different letters in the column within the same factor are significant different according to the least significant difference (LSD) test at $P \leq 0.05$.
‡ Alf, RC, and PR represent alfalfa, red clover, and perennial ryegrass, respectively. The cover crops were interseeded with soybean at planting (0 WAP) or 2 wk after planting (2 WAP) soybean in 2002, and corn was planted in 2003.

compared with its control. The yields in other cover crop treatments were numerically lower than their controls, but the differences were not significant ($P > 0.05$).

Corn Yield in 2003

At Waseca, neither soybean cultivar nor cover crop treatment affected 2003 corn yield (Table 5). At Lamberton, while the soybean cultivar in 2002 did not affect 2003 corn yield, the cover crop treatments affected corn yield. Alfalfa and red clover planted 0 WAP and perennial ryegrass planted 2 WAP after planting soybean in 2002 significantly suppressed corn yield in 2003 compared with their respective controls. Red clover planted at 0 WAP resulted in lower corn yield compared with red clover planted at 2 WAP (Table 5). At Rosemount, there was an interaction between soybean cultivar and cover crop on the 2003 corn yield (Tables 5 and 6). SCN-susceptible soybean resulted in lower corn yield compared with SCN-resistant soybean in plots of no-cover with glyphosate, and red clover planted at 2 wk. In perennial ryegrass plots planted 0 WAP, the susceptible soybean resulted in higher yield than the resistant soybean. No soybean cultivar effect on corn yield was observed for other cover crop treatments (Table 6). In the plots planted with SCN-susceptible soybean in 2002, red clover planted either 0 or 2 WAP reduced corn yield compared with the control (Table 6). In the plots planted with SCN-resistant soybean in 2002, corn yield in plots where red clover and alfalfa were planted 0 WAP was lower than the control. In plots with SCN-susceptible soybean in 2002, perennial ryegrass planted 0 WAP resulted in higher 2003 corn yield than when planted 2 WAP but the effects were reversed in plots with SCN-resistant soybean (Table 6).

DISCUSSION

The overall effects of the individual cover crops on SCN populations and soybean and corn yields were not consistent across the three sites and among the sampling times. In general, there was no dramatic reduction of egg population density by the cover crops compared with no-cover controls. Red clover and alfalfa interseeded in the soybean crop appeared to reduce the nematode egg population densities, but the effects were minimal and inconsistent. While perennial ryegrass did not affect SCN egg population density in most cases, higher egg population densities in the perennial ryegrass treatment were observed at Waseca.

The reduction of SCN populations by alfalfa and red clover appeared to be mainly due to the suppression of soybean growth by the two cover crops. However, a significant positive correlation between the final SCN population density in 2002 and soybean yield was observed only at Rosemount (data not shown). It is possible other mechanisms may also be involved in low-

Table 6. Interaction between soybean cultivar and cover crop treatments in 2002 on 2003 corn yield at Rosemount, MN.†

Cover treatment‡	Soybean cultivars in 2002	
	SCN-susceptible	SCN-resistant
	kg ha^{-1}	
No cover/glyphosate	7 956bcdB	8 754aA
No cover/imazethapyr	8 837a	8 693a
No cover/quizalofop-p-ethyl + bentazon	8 362abc	8 206abc
Alf, 0 WAP/imazethapyr	8 511abc	7 680bc
RC, 0 WAP/imazethapyr	7 559de	7 639bc
Alf, 2 WAP/imazethapyr	8 764a	8 457ab
RC, 2 WAP/imazethapyr	6 977eB	8 167abcA
PR, 0 WAP/quizalofop-p-ethyl + bentazon	8 568abA	7 488cB
PR, 2 WAP/quizalofop-p-ethyl + bentazon	7 850cd	8 610a

† The values are means of eight replicates. The values followed by different lowercase letters in the same column or the different uppercase letters in the same row are significant different according to the least significant difference (LSD) test at $P \leq 0.05$.
‡ Alf, RC, and PR represent alfalfa, red clover, and perennial ryegrass, respectively. The cover crops were interseeded with soybean at planting (0 WAP) or 2 wk after planting (2 WAP) soybean in 2002, and corn was planted in 2003.

ering the SCN populations but were not determined in this study.

Alfalfa and red clover are leguminous plants, and it is possible that the exudates from these two crops may induce SCN hatch (Aiba and Mitsui, 1995). Because red clover and alfalfa are nonhosts or poor hosts, they may act as a trap crop and lower SCN population density compared with the fallow control in absence of the primary host soybean (Shimizu et al., 1989; Kushida et al., 2002; Vetter et al., 2005). Thus, it is possible that this mechanism as trap crop was also involved in lowering the SCN population densities in this study.

The increase of SCN population density in perennial ryegrass treatment at Waseca compared with its control is interesting, but the reason is unclear. Perennial ryegrass is a non-host of SCN, thus the cover crop may protect nematodes in some other ways. In a previous study, presence of perennial ryegrass reduced the ecotoxicological effect of metal pollutions on nematode communities (Korthals et al., 1998). The presence of cover crops in soybean fields may maintain soil moisture, and reduce SCN mortality compared with no-cover treatment (mostly bare soil in early season). In perennial ryegrass, this positive effect on SCN population might be observed because there was no or little other negative effect. In contrast, red clover and alfalfa treatments may have other negative effects on SCN such as stimulating eggs to hatch. Consequently, the positive effects of the cover crops on SCN, such as maintaining soil moisture, were not observed for alfalfa and red clover treatments.

In Waseca, significant difference in SCN population density among the herbicide treatments in the no-cover plots was observed at planting corn in 2003. It is unclear whether the difference was resulted from the herbicide treatment or experimental error.

Change of SCN population over a growing season depends on host status and initial population. The higher PCF during the soybean growing season at Waseca compared with Lamberton and Rosemount was due to the lower initial population level at Waseca. The higher PCF in 2003 in plots where SCN-resistant soybean was grown in 2002 compared with the SCN-susceptible soybean treatment was due to the lower initial population density since the survival of SCN is density-dependent (Todd et al., 2003).

This study suggests that the cover crop may affect soybean growth and yield. This effect depends on weather conditions, soil environments, and planting dates. Planting these cover crops at the same time of planting soybean is not recommended due to competition with soybean plants and suppression of soybean yield. It appeared that planting red clover and alfalfa 2 WAP after planting soybean also had some negative effect on soybean yield. Thus later planting dates need to be considered for the use of these cover crops in Minnesota soybean/corn production system. Although red clover and alfalfa had only little impact on SCN population, it may add value to use of these plants as cover crops for soybean/corn production system if they are economically and environmentally beneficial as cover crops interseeded in soybean. Thus, further study to evaluate the effectiveness of delayed planting dates for cover crops may be useful when they are used as an SCN management strategy as well as for other agronomical considerations.

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